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Precise nitrogen management: Away forward for enhancing resources use efficiency and productivity of direct seeded rice: A review

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Abstract

Presently, 50 percent of the human population relies on synthetic nitrogen (N) fertilizer for food production. In agriculture of subsistence during pre-chemical era, biological N2 fixation (BNF) was the primary source of reactive N but, in recent decades chemical N fixation (synthetic N) has become more important in global agriculture. Today, synthetic N fertilizer introduces reactive N of over 100 Tg N year-1 into the global environment to increase food production. Although this has sustained the large human population in meeting dietary needs, a large agriculture area in the world still lacks available N to sustain the crop production. As regards of split N application the yield and yield contributing parameters were significantly influenced by split application of N. With increase in the number of splits application along with basal application found more effective for improving the production of direct seeded rice. This article gives broad idea about Nitrogen status globally and nitrogen management in direct seeded rice.

Keywords: Precise nitrogen management, seeded rice

1. Introduction

With dearth of fresh water availability, irrigated rice systems in Asia are switching towards water saving direct seeded or alternate wetting and drying (Farooq *et al*. 2011). Development of these systems involve identification of suitable cultivars combined with traits of high yield stability and resource use efficiency when grown under different sets of nutrient and water management practices (Lafitte *et al*. 2002). Rice under aerobic conditions utilize NO3-N which reduces NH3 voltalization. However, during wetting-drying cycles, decomposition of organic matter causes ammonification of N subjected to NH3 losses and upon soil drying, increased nitrification-denitrification process increases N2O losses (Sahrawat 2009). Aerobic rice can uptake higher N and improve biomass, however may subject to higher losses if available in more quantity than its uptake by crop and utilized for microbial biomass (Belder *et al*. 2005a, b). Studies indicate that aerobic rice grown with both NH4 and NO3 produce more number of panicles and 1000 grain weight than NH4 or NO3 supply alone. This response is attributed to improved total N uptake and biomass resulting in increased nitrogen use efficiency. The study also showed that under NO3 supply, little risk of its pollution with N fertilization in upland soil was found (Qian *et al*. 2004). Khindand Ponnamperuma (1981), comparing different irrigation regimes, soil types and N levels found non-significant effect of soil drying treatments, N levels and season in suppression of growth, yield and N uptake in rice. Due to absence of NO3 after soil drying, denitrification losses were negligible on flooding (Pillai and De 1979). Nonetheless, most of the studies showed response of aerobic rice to total N uptake, recovery efficiency and yield (Awan *et al*. 2014, Mahajan *et al*. 2012) [43] and no information with effect of nitrogen splitting on N dynamics at phenologically important growth stages particularly at physiological maturity and its relationship with crop yield are available.

Global N Consumption and Demand for Major Cereals

During and after the Green Revolution in the 1960s, synthetic N fertilizer has played a crucial role in increasing crop productivity to alleviate the growing food insecurity caused by a worldwide increase in population. Since then, the application of synthetic N on fertilizer-responsive and lodging-resistant short-stature cultivars of cereals boosted the food

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production by about 260 percent (an average growth of 6.4 percent per year). Today, fertilizer N supplies approximately 45 percent of the N input for global food production with the global use of around 100 million metric tons (Mt) (FAO, 2010). Nearly half of this N is consumed by three most important cereals (rice, wheat and maize) with 50-year (2010-2010) average application rates (kg ha crop-1) of 77, 69 and 51 in maize, rice and wheat, respectively (Ladha *et al* 2016). In 2010, maize and rice approached similar N application rates (114 kg ha-1) followed by wheat (99 kg ha-1). It is projected that to meet the global cereal demand of three billion tons by 2050 and with projected increase of 7 percent in harvested area, fertilizer application rates to the three cereals must increase by about 65 percent, assuming no change in N use efficiency of the crop. In terms of global quantity of synthetic N, the increase would be from 51.8 Tg in 2010 to 85.4 Tg in 2050.

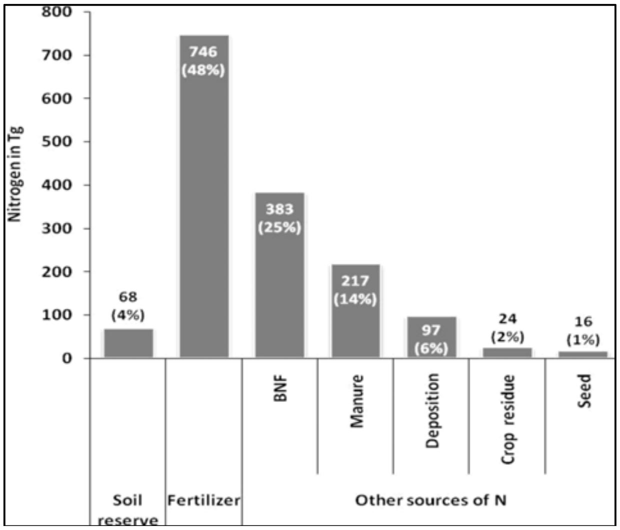

Fig 1: Global estimates of sources of N in major cereal crop production systems: total (Tg) for 50 years (1961-2010). Source Ladha *et al* (2016).

The pertinent literature on management of N in direct seeded rice (DSR) for higher yield and N use efficiency has been reviewed under the various heads.

Effect of different rates of N on yield and yield attributes

Nitrogen is one of the most yield limiting nutrients for annual crops around the world and its efficient use is important for economic sustainability of cropping systems. Recovery of N in crop plants is usually less than 50 percent worldwide for aerobic crops and 30-40% for transplanted rice (Raun and Johnson 1999) [63]. The low recovery of N is associated with its high losses by leaching, volatilization and denitrification. Since the concept of DSR in northwestern Indo Gangetic plains (Punjab) is new, relatively few insights into N dynamics and fertilizer N use exist. In puddled transplanted rice soils, ammonium is the dominant form of available N which is lost through ammonia volatilization (Vlek and Craswell 1981) [77] and some of the ammonium is nitrified in oxidized soil zones (De Datta *et al* 1988) [24] which is subsequently de-nitrified thus lost to the atmosphere as N2 and N2O or leached down beyond rooting-zone (De Datta 1981) [23]. Since nitrate is barely present in flooded rice soils, very little nitrate-N is leached to the groundwater (Bouman *et al* 2002) [16]. In aerobic systems, on the other hand, the dominant form of N is nitrate and relatively little ammonia volatilization can be expected after fertilizer N application. The application of irrigation water will create soil moisture conditions close to saturation immediately following irrigation and below field capacity a few days later. The differences in soil N dynamics and pathway of N losses between flooded and aerobic systems may result in different fertilizer N recoveries. The alternate moist and dry soil conditions may stimulate nitrification-denitrification processes in D-DSR, resulting in a higher loss of N through N2 and N2O (Prasad 2011) [58]. In the absence of transplanting, the roots of D-DSR are located in the shallow surface soil, which results in a relatively lower uptake of N (Zhang and Wang 2002) [86]. These observations suggest the fertilizer rates recommended for transplanted rice may not be optimal for D-DSR.

In an experiment, N transformations in transplanted rice and wet-direct seeded rice (W-DSR) were studied and they concluded that depletion of exchangeable NH4+-N was attributed primarily to plant N uptake (Diekmann 1990) [25]. Exchangeable NH4+-N depletion was faster in W-DSR, presumably because of its higher growth rate during the vegetative stage and its more rapid N uptake. Because transplanted rice suffered from transplanting shock, its plant N uptake was lower than that of W-DSR during the first 20 days after fertilizer application, delaying exchangeable NH4+-N depletion by plant absorption in transplanted rice. The rate and timing of N fertilizer need to be adjusted to meet the crop's demand at different growth stages. Timely and split application of N allows more efficient use of N throughout the growing season as it provides desired amounts of N to the crop during peak periods of growth and may reduce leaching of nitrate in the soil (Fageria 2010, Lampayan *et al* 2010) [27, 38]. Nitrogen management in rice is becoming more important as concern grows about the high cost of this input and nitrate pollution of surface and ground waters in agricultural areas (Xue *et al* 2008) [80]. Synchrony of N supply with crop demand is essential in order to ensure adequate quantity of uptake and utilization, optimum yield, quality and avoiding negative environmental impacts. Improved N-use efficiency can reduce cost of crop production as well as environmental pollution. The rate and timing of N application is important for improving N-use efficiency and crop yields (Fageria and Baligar 2005) [28]. Application of N fertilizer increased grain yield of rice when the rice was exposed to water scarcity (Castillo *et al* 2006) [19]. In rice production, efficient use of fertilizer N is a critical factor in achieving high and stable yield, while minimizing negative effects to the environment (Ntamatungiro *et al* 1999, Hirel and Lemaire 2005, Tylaran *et al* 2009) [47, 29, 76]. The fertilization for transplanted rice, in which most N was applied as basal fertilizer (40-60 percent of total fertilizer–N), was inherited in the D-DSR cultivation without improvement (Yin *et al* 2004) [42]. This leads to a low use efficiency of N by D-DSR and a high production cost. A reasonable fertilizing scheme is important to control N cycling in rice (Aulakh and Bijay-Singh 1997) [6]. Mahajan *et al* (2011) [41, 42] conducted an field experiment with a combination of three N levels (120,150 and 180 kg ha-1) and three timings of fertilization (three equal split doses at sowing, 21 and 42 days after sowing [DAS]); four equal split doses at sowing, 21, 42 and 63 DAS and four equal split doses at 15, 30, 40 and 60 DAS. The crop did not respond to increasing levels of N from 120 to 180 kg ha-1 when applied in three split doses. However, increasing N application to 150 kg ha-1 when applied in four split doses with no N at sowing time resulted in 7.55 and 7.66 Mg ha-1 yields in 2009 and

2010, respectively; highest among all treatments. Application of 150 kg N ha-1 in four splits with no-N at sowing resulted in 9 to 12, 19 to 24, and 5% increase in panicle number m-2, filled grains panicle-1, and 1000 grain weight, respectively, over the application of 120 kg N ha-1 in three split doses with N application at sowing. The relative contribution of mean preanthesis assimilates to grain increased from 23% at 120 kg N ha-1 in three split doses to 40% at 150 kg N ha-1 applied in four split doses with no-N at sowing. The study further revealed that application of N at anthesis may further boost the productivity of D-DSR. From these results, it could also inferred that, for D-DSR, application of N at sowing time can be skipped because it may not be immediately used by the emerging seedlings. Sharma *et al* (2007) [66] conducted an experiment during the rainy season of 2002 and 2003 to study the effect of three levels of N (40, 80 and 120 kg ha-1) in D-DSR and observed that application of 120 kg N ha-1 gave significantly higher grain and straw yields over 40 and 80 kg N ha-1 during both years. They observed that there was an increase in grain yield, owing to application of 80 and 120 kg N ha-1 over 40 kg N ha-1, of 26.6 and 32.4%, respectively. They further revealed that significant increase in grain and straw yields could be attributed to the fact that N application improved the N, P and K uptake by the crop plants and ultimately photosynthetic activities, resulting in growth and yield attributes which laid down the foundation of higher yield. Singh and Tripathi (2007) [69] conducted an experiment during rainy (kharif) season of 2002 and 2003 to study the effect of N on yield of D-DSR at Faizabad in silty loam soil. The treatments comprised five N levels (0, 40, 80,120 and 160 kg ha-1). Half the N as per treatment and full dose of P (26 kg ha-1) and K (50 kg ha-1) were applied at sowing and the remaining half dose of N was top-dressed in two equal split doses at 30 DAS and at panicle-initiation stage. They observed significant increase in grain yield up to 120 kg N ha-1 (5.64 t ha-1) and there was no further increase at 160 kg N ha-1 (5.89 t ha-1). This increase in grain yield was mainly due to significant increase in test weight and panicles m-2, which have positive correlation with grain yield. Mahajan *et al* (2012) [43] studied the effect of four levels of N (0, 60, 120 and 180 kg ha-1) and N was applied in four equal split doses at 15, 30, 45 and 60 DAS in all the levels in D-DSR. They concluded that the effect on grain yield and yield attributing characters viz., plant height, grains panicle-1 and test weight was significant up to a level of 120 kg N ha-1. Nitrogen application at 180 kg ha-1 did not bring any significant effect on the grain yield and yield parameters over 120 kg ha-1 level in D-DSR. Mahajan and Timsinia (2011) [41, 42] studied the effect of three levels of N (120, 150 and 180 kg ha-1) in D-DSR and revealed that application of 150 kg N ha-1 produced significantly higher grain and straw yield over 120 kg N ha-1 but at par with 180 kg ha-1. They also concluded that spikelet sterility increased by 22% at highest N level (180 kg ha-1) as compared to 120 kg N ha-1 and at par with 150 kg ha-1. They found that weed dry matter remained statistically the same with N application of 120 and 150 kg ha-1, as a result of which crop N-use efficiency increased with N application of 150 kg ha-1 and ultimately resulted in more yield. But further increase in N level from 150 to 180 kg ha-1 resulted in significant increase in weed biomass as a result of which grain yield did not increase further. Yong *et al* (2010) [83] performed an experiment to identify an effective fertilizing scheme for D-DSR in East China. Based on local traditions, 3 typical fertilizer schemes were evaluated in consideration of ensuring a certain rice yield and relatively low N loss. The fertilizer N was applied at basal, seedling, tillering, jointing and panicle stage. The fertilizer schemes were designated as FS-1 were N was applied in equal split doses of 20% of 270 kg N ha-1, those for FS-2 were 30%, 30%, 0%, 25% and 15% of 270 kg N ha-1 and 15%, 20%, 25%, 20% and 20% of 220 kg N ha-1 for FS-3, respectively. The rice yield with FS-1, FS-2 and FS-3 was 8.53, 7.78 and 8.62 t ha-1, respectively. The results show that FS-3 was significantly better than FS-2 but it was at par with FS-1. They suggested that N for D-DSR should be applied as top dressing fertilizer when rice growth require more N and not as basal fertilizer as in transplanted rice cultivation. The main demand for nutrients by D-DSR occurs during the middle stage of its growing season. Under FS-1, FS-2 and FS-3, N loss was 91.4, 103.1 and 70.5 kg ha-1, respectively. As a result, FS-3 was used in this study for D-DSR, which resulted in highest rice yield and reduced the requirement of total N fertilizer by 50 kg N ha-1. This was due to the good utilization of N and more fertilizer was applied as top dressing fertilizer in FS-3 when rice crop require more N. Zhang *et al* (2009) [85] investigated the yield and dry matter translocation of D-DSR (cultivar HD 297) in response to N application, grown under different irrigation regimes at two sites close to Beijing, North China. Fertilizer N rates were 0, 75, and 150 kg N ha-1 applied in split dressings according to regional recommendations for D-DSR. The application of N at the rate of 75 kg ha-1 increased grain yield from 3.4 to 4.4 t ha-1. But there was no significantly difference between 75 to 150 kg N ha-1 on either grain or straw yield. Grain yield showed significantly positive correlations with above ground dry matter, number of panicles m-2 and spikelets m-2, which are yield components determined before anthesis. Grain yield showed little correlation with the percentage of filled grains and 1000-grain weight, all being determined after anthesis. The contribution of pre-anthesis assimilates to grains increased from 12% (N0) to 55% (N150), whereas the contribution of post-anthesis assimilates to grains decreased from 88% (N0) to 46% (N150). This indicates that post-anthesis dry matter accumulation is crucial for improving grain yield. Differences in correlations between grain yield and the yield components that were determined by pre anthesis growth and post-anthesis growth suggest that the timing and amount of N supply realized here did not adequately match crop N demand between the preanthesis and post-anthesis periods. Before anthesis, dry matter accumulation increased with N application, but after anthesis, dry matter accumulation decreased with increasing N application.

Ramesh *et al* (2009) [60] conducted an experiment to find out the optimum N level and effective weed management practice for D-DSR. Three N level (100, 125 and 150 kg N ha-1) in main plots and five different weed management practices (hand weeding twice, mechanical weeding twice, pre-emergence application of pendimethalin at 0.75 kg ha-1 + one hand weeding on 45 DAS, pretilachlorplus safener at 0.4 kg ha-1 + one hand weeding on 45 DAS and unweeded control) in sub plots were studied. Results revealed that tiller population, number of panicles, grains panicle-1, 1000-grain weight and grain yield increased significantly when N was increased to 125 kg ha-1 but further increase in N failed to increase significantly the yield and yield attributes. This was mainly because of increased N supply at distinct physiological phases which would have supported better assimilation of photosynthates and in turn better yield attributes. Lawal and Lawal (2002) [39] reported that maximum grain yield of rice was obtained with 120 kg N ha-1 which was significantly higher than those obtained with 80 kg N ha-1. The application of fertilizer at the rate of 80 kg N ha-1 significantly increased crop growth rate, number of ear bearing tillers m-2, and percent filled grains of rice. Whereas plant height, 1000-grain weight and grain weight panicle-1 responded to fertilizer up to 120 kg N ha-1. Pandey *et al* (2000) [51] conducted an experiment with five N levels (0, 40, 80, 120 and 160 kg N ha-1) in D-DSR and revealed that the application of N up to 120 kg N ha-1 significantly increased the grain yield (4.05 t ha-1), panicles m-2 (267) and grains panicle-1 (99) than 80 kg N ha-1 but it was at par with 160 kg N ha-1. Jong *et al* (1999) [33] observed that the concentrations of N in flag leaf were positively correlated with the amount of N applied and also with the grain yield of D-DSR. Panicle number, spikelet number, 1000-grain weight, percentage of ripened grain and grain yield increased significantly with increase in the amount of N applied up to 150 kg N ha-1. Roy and Mishra (1999) [64] conducted an experiment on D-DSR in which three N levels (0, 40 and 80 kg N ha-1) when applied in three split doses i.e. ¼ at sowing, ½ at tillering stage and ¼ at panicle initiation stage. Highest grain yield was recorded in 80 kg N ha-1 (2.60 t ha-1) and it was significantly better than 40 kg N ha-1. They observed significant increase in test weight, panicles m-2, panicle length and spikelets panicle-1 at 80 kg N ha-1 as compared to 40 kg N ha-1.

Kumar *et al* (1995) [36] concluded that with increase in N from 80 to 120 kg N ha-1 there was significant increase in the plant height, total tillers, dry matter accumulation, panicle number, grains panicle-1, and N-uptake as well as grain and straw yields. The higher level of N i.e. 160 kg N ha-1 did not further improve these characters. However, Prasad *et al* (1994) [57] conducted an experiment with four N levels of (0, 40, 80 and 120 kg N ha-1) in D-DSR. They observed that number of tillers, length of panicle, 1000-grain weight and leaf area index increased significantly up to 80 kg N ha-1, beyond which the differences were non-significant. Significant increase in grain yield was also reported up to 80 kg N ha-1. Thakur (1993) [75] revealed that with the increasing levels of N there was significant increase in growth and yield attributes significantly. Plant height, effective tillers m-2 and grains panicle-1 increased significantly up to 120 kg N ha-1, whereas length of panicle and 1000-grain weight increased only up to 80 kg N ha-1. Prasad *et al* (1992) [59] conducted an experiment with four N levels of (0, 40, 80 and 120 kg N ha-1) in D-DSR. They observed that grain yield of rice was significantly increased only up to 80 kg N ha-1 beyond which the differences were non-significant. The leaf area index, number of tillers, length of panicle and 1000-grain weight also increased significantly up to 80 kg N ha-1. Similarly, Kumar *et al* (1986) [37] reported that grain yield and yield attributes of D-DSR were significantly influenced by N and maximum grain yield of 4.7 t ha-1 recorded with 80 kg N ha -1 was due to the highest number of panicles m-2 (459), panicle length (21.5 cm) and grains panicle -1 (97.8) which were significantly superior to 40 kg N ha -1. Patel *et al* (1986) [54] observed that N application significantly increased the grain yield with increasing levels of N up to 180 kg N ha-1. However, considering the economics (net incremental cost: benefit), application of 120 kg N ha-1 was found to be more remunerative than 180 kg N ha-1. De Datta *et al* (1988) [24] evaluated W-DSR and transplanted rice under similar N management practices and found that mean N plant recovery was greater for W-DSR than for transplanted rice. With applied urea, mean 15N plant recovery was greater for W-DSR (47%) than for transplanted rice (37%). Without applied N, mean grain yield of transplanted rice was 0.3 t ha-1 lower than that of W-DSR. These results suggest that there is considerable potential exists to increase N use efficiency and grain yield in W-DSR by manipulating N fertilizer management practices. Alagesan and Raja Babu (2011) [1] concluded that the effect on grain yield and yield attributing characters (number of tillers, filled grains per panicle, percentage of unfilled grains per panicle and test weight) was significant up to a level of 120 kg N ha-1. Nitrogen application at 160 kg ha-1 did not bring any further significant improvement in the grain yield and yield parameters over 120 kg ha-1 level. The grain yield of W-DSR declined significantly when N was applied at 200 kg ha-1. Yadvinder-Singh *et al* (2007) [81] revealed that grain yield of W-DSR increased significantly up to 120 kg N ha-1. Beyond 120 kg N ha-1, no significant increase in grain yield was observed but its higher application resulted in significantly higher production of rice straw. Beura and Reddy (2003) [12] studied the effect of four levels of N (0, 60, 120 and 180 kg N ha-1) on grain yield of W-DSR and revealed that application of 120 kg N ha-1 recorded significantly higher grains panicle-1 (104.7), 1000-grain weight (25.3 g) and grain yield (3.7 t ha-1) than 60 kg N ha-1. However, grain yield and yield attributes was at par with 180 kg N ha-1. Dar *et al* (2000) [22] carried out an experiment consisting of five N levels (0, 30, 60, 90, 120 and 150 kg N ha-1) in W-DSR to find out the optimum N level. They observed that grain yield of rice was significantly increased only up to 120 kg N ha-1 beyond which the differences were non-significant. The leaf area index, number of tillers, panicles m-2 and grain panicle-1 also increased significantly up to 120 kg N ha-1, whereas, panicle length was increased significantly only up to 90 kg N ha-1 and 1000-grain weight showed significant increase only up to 60 kg N ha-1. Increasing N level up to 120 kg N ha-1 significantly improved grain yield over 30, 60 and 90 kg N ha-1 with a magnitude of superiority of 53, 20 and 13%, respectively. However, straw yield increased significantly up to 150 kg N ha-1 and harvest index only up to 90 kg N ha-1.

Effect of various schedules of N application on yield and yield attributes.

Split application of fertilizer especially N is necessary not only to obtain high grain yields but also to minimize lodging and pest incidence in D-DSR. Results of direct seeding trails conducted in Central Luzon Philippines, indicate that two split doses at 21 and 35-42 DAS or three split doses at 21, 35 and 49 DAS in broadcast sown rice will optimize both grain yield and agronomic N-use efficiency (IRRI-CREMNET 1998, Balasubramanian *et al* 2000) [31, 10]. Most farmers in the Philippines apply fertilizers in 2-3 split doses from 15-20 to 49 DAS (Rao and Moody 1994) [61]. Delaying the first N application until 10 DAS in Vietnam (Hung *et al* 1995) [30] and until 30 DAS in Malaysia (Supaad and Cheong 1995) [74] and Thailand (Vongsaroj 1995) [78] did not decrease yields.

Sharma *et al* (2007) [66] conducted an experiment on D-DSR in which the treatments consisting of 3 split doses of N, viz. ½ N at 20 days after sowing (DAS) + ¼ at tillering (T) + at panicle initiation (PI); ¼ at 20 DAS + ½ at T + ¼ at PI; ½ at sowing + ¼ at tillering (T) + ¼ at PI and ¼ N at sowing + ½ at T + ¼ at PI. The highest grain (3.06 t ha -1) and straw yields (3.56 t ha-1) were recorded with the application of ½ N at 20 DAS+ ¼ N at tillering + ¼ N at PI, which was significantly superior to remaining schedules. The results clearly indicates that skipping the N dose at sowing and applying the same at 20 DAS was more favourable for higher grain and straw yields, owing to higher N, P and K uptake, resulting in better yield and yield attributes. Higher N, P and K uptake by the crop in these treatments could be attributed to more availability of nutrients in soil owing to less depletion of nutrients by weeds. Zhang *et al* (2009) [85] conducted an experiment in which N was applied in three split doses; 30% at sowing, 40% at tillering and 30% at panicle initiation in D-DSR and observed that less N application before anthesis and more N application at or after anthesis may increase post anthesis dry matter accumulation and grain filling. The most appropriate time of N application to rice is panicle initiation, which produced maximum plant height, grains panicle-1 and grain yield (Bacon 1980) [7]. Singh *et al* (2005) [70] observed that there was highest grain yield (4.12 t ha-1) when N was applied in three split doses (¼ basal + ½ at tillering + ¼ at panicle initiation) as compared to the three split doses (½ basal + ¼ at tillering + ¼ at panicle initiation) owing to the lower weed density and weed dry weight. Higher dose of N as basal appeared in boosting initial weed growth and hence increased the weed biomass per unit area in D-DSR. Singh *et al* (1999) [71] conducted an experiment on D-DSR in which there were different schedules of N application i.e. control; basal; ½ basal + ½ at panicle initiation; ¾ basal + ¼ at panicle initiation and ½ basal + ¼ at tillering + ¼ at panicle initiation. They concluded that among different schedules of N application, three split doses of N application gave significantly higher yield (5.50 t ha-1) over the rest of schedules of N applications. The percent increase in grain yield under three split application (½ basal + ¼ at tillering + ¼ at panicle initiation) was of 46, 49 and 46% higher than the grain yield of basal; ½ basal + ½ at panicle initiation; ¾ basal + ¼ at panicle initiation, respectively. Pandey *et al* (1998) [50] carried out an experiment on D-DSR and concluded that application of ¼ N at sowing + ½ at tillering + ¼ at panicle initiation or 1/3 N at sowing + 1/3 at tillering + 1/3 at panicle initiation proved more efficient timings of N application as compared to ½ N at sowing + ½ at tillering or ¼ N at sowing + ¼ at early seedling + ¼ at tillering + ¼ at panicle initiation. This is due to the application of minimum dose of N at sowing was more favourable for higher grain (3.63 t ha-1) and straw yield (8.01 t ha-1), obviously owing to higher uptake of N resulting in better yield and yield attributes. Rathi and Sharma (1996) [62] also concluded that application of N in two equal split doses at sowing and 45 DAS gave lowest grain yield (2.67 t ha-1) whereas the grain yield increased by 9 and 13% when was applied in two equal split doses at 15 and 45 DAS and three equal split doses at sowing, 15 and 45 DAS. When half quantity of N was basally applied, it was probably not efficiently used by the young rice seedlings due to more weed infestation. But when N was applied in two equal split doses at 15 and 45 DAS following hand weeding, yield increased significantly. Nageswari and Balasubramaniayan (2004) [45] conducted an experiment to study the effect of delayed basal dressing and split applications of N in W-DSR. Basal N application treatments include: at sowing, 7, 14 and 21 DAS. The split application of N consisted of two equal split doses (50% basal and 50% panicle initiation); three equal split doses (50% basal, 25% at tillering and 25% at panicle initiation); four split doses (16.5% at basal, 33.5% at tillering, 33.5% at panicle initiation and 16.5% heading stage); five split doses (equally at basal, tillering, active tillering, panicle initiation and heading stage). Among the N split doses, five split applications produced more leaf-area index and dry matter. Basal dressing of N at 21 DAS produced more number of panicles, panicle weight and filled grain percentage. The highest grain yield (4.36 t ha-1) was obtained under delayed basal dressing of N at 21 DAS. The yield increase due to this treatment was 17.3% over basal N application. Five split application of N recorded higher grain yield (4.24 t ha-1) than other methods of N split application. Effective utilization of N at critical stages of crop growth ultimately led to higher grain yield. Nitrogen uptake (109.7 kg ha-1) was significantly higher due to delayed application of basal N at 21 DAS at harvest as compared to the other treatments of split application of N. With respect to N scheduling, split application of N at five stages significantly increased the N uptake. Bayan and Kandasamy (2002) [11] laid out an experiment on W-DSR with two split schedules of N i.e. in four split doses (1/6 at 10 DAS, 1/3 at tillering, 1/3 at panicle initiation and 1/6 at heading stage) and five equal split doses of N as basal, at 10 DAS, tillering, panicle initiation and at heading stage. Application N in four split doses recorded significantly more effective tillers m-2 (432), grains panicle-1 (96.6) and grain yield (5.82 t ha-1) as compared to that of five split doses in which effective tillers m-2 (409), grains panicle-1 (87.1) and grain yield (5.67 t ha-1). Though both these split application of N showed no significant influence on 1000-grain weight. This might be due to better growth of rice as evidenced by higher leaf area index and plant dry matter. Dar *et al* (2000) [22] studied the effect of split application on grain yield of W-DSR. There were three different schedules of N application i.e. S1 (½ basal + ¼ tillering, ¼ at panicle initiation); S2 (1/3 basal + 1/3 tillering, 1/3 at panicle initiation) and S3 (¼ basal + ¼ at tillering + ¼ at panicle initiation, ¼ heading stage), respectively. Applying N in four split doses (S3) significantly higher leaf area index than three split doses (S1 and S2). Among various yield attributes panicles m-2, panicle length and grains panicle-1 increased significantly with four split doses (S3) than three split doses (S1 and S2). However, sterility percentage and 1000-grain weight remained unaltered under various in N split doses. The favourable effects of more number of N split doses (S3) on growth and yield attributes led to increased grain yield significantly by 2.6 and 4.8% over S1 and S2, respectively. Straw yield exhibited similar trend as that of grain yield.

Effect of different rates and schedules of N on N uptake and N-use efficiencies (NUE)

Rathi and Sharma (1996) [62] studied the effect of interaction between rate and time of N application on grain yield of rice was significant. However, at higher rate 90 kg N ha-1, in two equal split doses at 15 DAS and 45 DAS and three equal split doses at sowing, 15 DAS and 45 DAS gave significantly higher grain yield than 30 and 60 kg N ha-1 in two equal split doses at sowing and 45 DAS. This indicates that application of N at sowing is not beneficial for D-DSR, confirming the findings of Choubey *et al* (1985) [21]. There was increase in the growth, yield components, yield and N uptake with the increased levels of N up to 80 kg N ha-1 in W-DSR (Bhattacharyya and Singh 1991). Application of 80 kg N ha-1 in four split doses with basal dose (4.21 t ha-1) proved best followed by that without basal dose (10 DAS) (4.18 t ha-1) proved better than that with the basal or without basal dose (10 DAS) in three split doses. Application of 40 kg N ha-1 produced 58% more grains over no N control whereas the respective increases with 80 kg N ha-1 10.9% over that of 40 kg N ha-1. These increases in grain yields due to increase in levels of N application and there was corresponding increases in growth and yield-contributing characters. Singh and Tripathi (2007) [69] revealed that total N uptake increased significantly with every increase in the rate of N up to 120 kg ha-1 beyond this there was no significant increase in total N uptake in D-DSR. The better total N uptake was associated with its better growth and development, resulting in higher yield. Highest total N uptake was recorded with 160 kg N ha-1 which showed an increase of 351, 130, 39 and 9.6% over that of 0, 40, 80 and 120 kg N ha-1, respectively. However, total N uptake at 120 kg N ha-1 was at par with 160 kg N ha-1. Similarly, results of another study exhibited that an increase in N application level had positive impact on N uptake by crop. At 120 kg N ha-1 N uptake by grain (38.6 kg ha-1) was significantly higher as compared to 40 (25.7 kg ha-1) and 80 kg N ha-1 (34.2 kg ha-1). Nitrogen uptake by straw also shows the similar trend as that of grain. Total N uptake by D-DSR was significantly higher in 120 kg N ha-1 than 40 and 80 kg N ha-1 (Sharma *et al* 2007) [66]. Mahajan *et al* (2011) [41, 42] concluded that N uptake in grain and total N uptake were significantly influenced by N rates and split doses, while straw N uptake was not affected. At each N level i.e. 120, 150 or 180 kg ha-1, four split doses had significantly higher N uptake in the grains than three split doses. Grain N uptake was significantly higher when N was applied at 150 kg ha-1 in four split doses without basal at sowing than 120 kg N ha-1 applied in three split doses with basal at sowing. However, there was not any significant effect on N uptake in grain with further increase in N to 180 kg ha-1. Total N uptake also showed the similar trend as that of N uptake in grain. Sharma *et al* (2007) [66] concluded that highest total N uptake (57.3 kg ha-1) was recorded with the application of ½ N at 20 DAS+ ¼ N at tillering + ¼ N at PI, which was significantly superior to remaining schedules (¼ at 20 DAS + ½ at tillering + ¼ at PI; ½ at sowing + ¼ at tillering + ¼ at PI and ¼ N at sowing + ½ at T + ¼ at PI). This clearly indicate that skipping the N dose at sowing and applying the same at 20 DAS was more favourable for higher N uptake, resulting in better yield and yield attributes. Sharma *et al* (2007) [66] concluded that agronomic efficiency (kg grain kg-1 N applied) showed a diminishing trend, as the levels of N increased from 40 to 120 kg ha-1. This was mainly due to denominator goes on increasing, whereas the numerator does not increase proportionately. As a result, agronomic efficiency at higher levels was low. Mahajan *et al* (2012) [43] also reported that agronomic efficiency (kg grain kg N applied-1) was increased significantly up to 120 kg N ha-1 beyond this there was significant decrease in agronomic efficiency. Dar *et al* (2000) [22] determined that the N uptake in grain of W-DSR was significantly influenced by applied N and maximum N uptake in grain recorded with 120 kg N ha –1 beyond which the differences were non-significant. Total N uptake also showed similar trend as that of N uptake by grain. With the increase in N dose from 30 to 150 kg ha-1, there was significant decrease in agronomic use efficiency and recovery efficiency (%) but physiological efficiency (kg grain kg-1 N uptake) was increased significantly up to 120 kg N ha-1.

Pandey *et al* (2000) [51] also found that total N uptake progressively increased with increasing levels of N up to 120 kg ha-1 beyond which there was no effect on total N uptake. This indicates that N application increased N supply to plant and increased N concentration and finally the uptake. With the increase in N dose from 40 to 160 kg ha-1 there was significant decrease in agronomic use efficient.

Conclusion

It can be understood after reviewing research conducted by various scientist at different location appropriate nitrogen management, scheduling and rate of nitrogen management in direct seeded rice leads to increase in the growth and yield of crop. Improved nitrogen management will certainly save the nitrogen loss with increasing in NUE. Time and rate of application is a key for higher profitability and productivity. Proper scheduling of nitrogen is necessary for improving its use efficiency depending on climatic situation, rainfall pattern and soil type. Nitrogen scheduling should be in such a way that must be synchronize with crop nitrogen demand which reduces its loss and increases its agronomic as well as recovery efficiency. Dry DSR is more prone to nitrogen losses which could be minimized through scheduling. Dose of nitrogen to crop is also equally important which should be assessed by conducting location specific experiments. In general, 120 to 150 kg N ha^{-1} has been reported at various locations depending upon crop varieties. Dose of nitrogen to crop is highly variable depending upon crop variety, growing situations, climate and soil type. Thus, there is urgent need to assess proper dose of nitrogen and its scheduling as per variable resource availability and climatic locations through location specific research.

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